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Special Issue on Recent Advances in Urban Transport and Logistics Through Optimization and Analytics

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Abstract. There has been a significant body of research on making urban transportation more efficient and sustainable. Planning of urban transportation services is challenging due to the crowded traffic infrastructure, increasing customer expectations, and rules set by municipalities. In recent years, a vast amount of urban transportation data has become available, e.g., travel times and customer demand data. This special issue intends to establish the landscape for the state-of-the-art in urban transportation involving optimization and analytics.

Keywords: urban transportation, transportation logistics

1. Positioning and Framework

Data-driven decision-making for logistics occurs at businesses around the world every day, but how to do it well is still an important area of research. Doing data-driven decision-making well requires new ideas to bridge the gap between logistics decision-making, data management, and analytics. Innovative theoretical research in combination with real-world implementation ideas is key. These were the ideas behind the theme of the 2015 Transportation Science and Logistics Workshop held in Berlin—"Recent Advances in Urban Transportation through Optimization and Analytics"—and this associated special issue.

In a recent city logistics review paper, Savelsbergh and Van Woensel (2016) review some relevant trends and advances in technology impacting urban transport and logistics. The authors discuss that the role of data, information, and analytics is an important facet, but not new. However, following the digital revolution, being able to quickly react to changes in data has become a new business opportunity. Quickly transforming data (with an increasing volume, velocity, and wide variety) into decisions is becoming more and more important, but also more challenging.

The Data-Driven Innovation (DDI) cycle (Figure 1) describes a sequence of important phases (OECD 2015). Datafication and data collection involves data generation through content digitization and monitoring of activities. The result of datafication and data collection can be seen as "Big Data" that needs to be exploited through advanced data analytics. Over time, a knowledge base evolves, leading to better decision-making. These decisions, in turn, lead to more or different data and are the start of a new cycle.

As data is collected and processed into a knowledge base (keeping track of history), we have better information on stochastics, time-dependency, and dynamics, improving offline decision-making (i.e., before execution). At the same time, real-time data streams enable improved online decision-making (i.e., real-time during execution). For example, if something unexpected happens (e.g., accident), plans (e.g., vehicle routes) can be adapted in real-time. Therefore, it is crucial to identify the relevant data that should trigger online decisions. At the same time, it is important to identify which data to include at offline decision moments. Some data might trigger online actions but might not improve the offline planning.

An adequate decision support systems involves connectivity, allowing data to be exchanged, shared, and connected. Once connectivity is in place, intelligence needs to be built in order to make use of these comprehensive data sources. This intelligence can have many forms. In a *Harvard Business Review* article on the Internet of Things (Porter and Heppelmann 2014), four stages (monitoring, control, optimization, and automation) for intelligence of connected products are discussed. The authors focus on products, but one can also use these stages to discuss the intelligence of other connected systems such as planning and scheduling tools. As pointed out by Savelsbergh and Van Woensel (2016), it is expected that future systems will function with a large amount of autonomy, indicating the need for advanced algorithms that utilize shared data.

In this special issue of *Transportation Science*, we present several papers considering new applications of urban transportation such as home delivery planning, shared mobility services, environmental friendly

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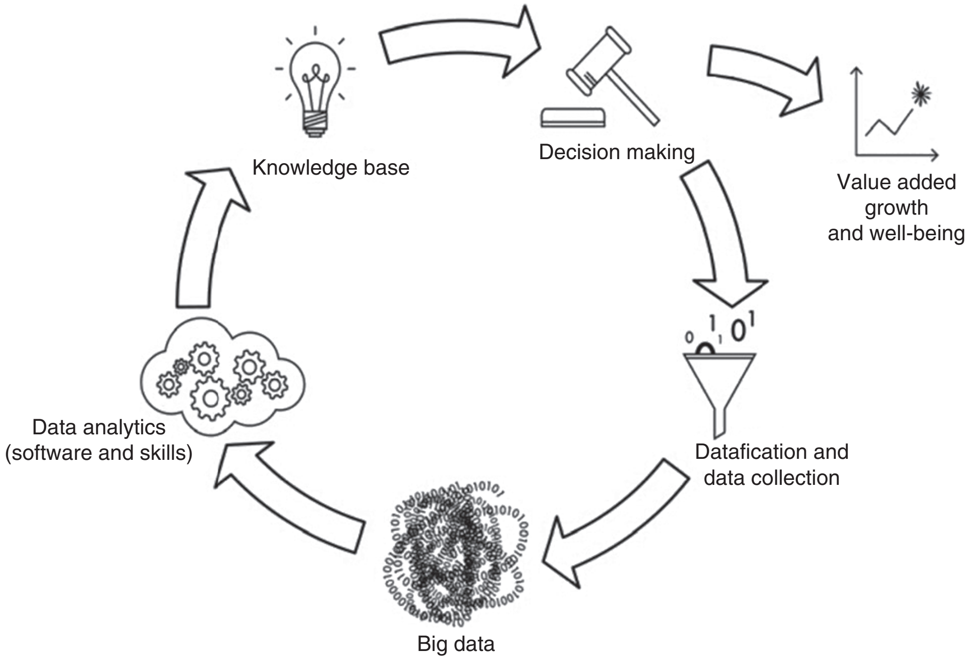
Figure 1. The Data-Driven Innovation (DDI) Cycle



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deliveries, and city logistics concepts. Every contribution demonstrates, in its own way, the use of analytics for optimization of urban transportation. In total, we received 49 submissions. After a thorough review process, 17 papers were accepted for this special issue. Nine papers deal with people-based transportation systems, while the remaining eight focus more on decision support for freight-based applications. In the following sections, we summarize the papers regarding people-based and then freight-based transportation.

2. People-Based Urban Transportation

Two papers consider the problem of optimizing the use of traffic signals for passengers traveling in cars. Baldi et al. (2019) show that traffic congestion can be mitigated via suitable control strategies. Their paper, "A Simulation-Based Traffic Signal Control for Congested Urban Traffic Networks," studies and analyzes the performance of an adaptive traffic-responsive strategy for traffic signal control. As the traffic network changes, new strategies are selected using information obtained from a traffic simulation model for an urban traffic network. With this approach, the authors demonstrate the efficiency of their traffic light control strategy. "Traffic Signal Optimization: Combining Static and Dynamic Models" presents a cyclically time-expanded network model for simultaneous optimization of traffic assignment and traffic signal parameters (Köhler and Strehler 2019). The developed mixed-integer programming models are tested on real-world instances and evaluated with simulation.

In this special issue, we have examples of both car-sharing and bike-sharing. Ströhle, Flath, and Gärttner (2019) explore the potential of spatial and temporal customer flexibility in order to achieve a better supply-demand alignment for car-sharing. Their paper "Leveraging Customer Flexibility for Car-Sharing Fleet Optimization" uses a real-world data set of 50,000 car-sharing reservations from a midsized German city. Using this data, the benefit of customer flexibility under offline and online optimization is evaluated. Moreover, the customer willingness to provide the needed flexibility is examined via a discrete choice experiment with 1,529 car-sharing customers. Bike-sharing systems typically face asymmetric demand, leading to imbalances, such as bicycles shortages or not enough vacant lockers for the return process. In their paper "Setting Inventory Levels in a Bike Sharing Network," Datner et al. (2019) aim to determine the appropriate re-positioning target levels for stations. The interaction between the stations, as a consequence of the user behavior, makes this problem particularly hard. A robust guided local search algorithm is introduced to set the target inventory levels.

Next are two papers which look at planning problems for public transit. The BusPlus project redesigns off-peak hours public transit service in Canberra, Australia. Using a multimodal hub-and-shuttle approach consisting of buses and shuttles, Mahéo, Kilby, and Van Hentenryck (2019) aim to decrease cost while maximizing traveler convenience. In their paper "Benders Decomposition for the Design of a Hub and Shuttle

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Public Transit System," a mixed-integer programming model is formulated and solved using a Benders decomposition approach. The hub-and-shuttle network design is validated using real-world data from Canberra's public transit system. Results show significant transit time reductions without increasing costs. Tight resource schedules in public bus transit are very prone to disruptions, causing delays and often cascading through the entire network. The authors of "Robust Efficiency in Urban Public Transportation: Minimizing Delay Propagation in Cost-Efficient Bus and Driver Schedules" focus on schedule robustness in their paper (Amberg, Amberg, and Kliewer 2019). Numerical experiments using real-world problem instances demonstrate the value of different scheduling schemes on robustness and cost-efficiency.

Finally, the last three papers on passenger transit involve private transportation choices for last-mile transportation. An extension of the classical dial-a-ride problem (DARP) is presented by Luo, Liu, and Lim (2019). Their paper, "A Two-Phase Branch-and-Price-and-Cut for a Dial-a-Ride Problem in Patient Transportation," extends previous work and enriches the problem setting with a number of real-life features, such as lunch breaks of staff members. Real-world data sets from the literature are used to show the capabilities of the developed algorithms. "Routing and Scheduling for a Last-Mile Transportation System" examines travel from the nearest public transportation node to a passenger's home or other destination (Wang 2019). This results in a routing and scheduling problem for a mixed fleet of delivery vehicles. This service faces batch demands, due to batch arrivals of passengers at the metro station or bus stop. Computational experiments show the value of such a last-mile transportation system in terms of reducing passenger waiting and riding time as compared to a more conventional system. Last, "A State Aggregation Approach for Stochastic Multi-Period Last-Mile Ride-Sharing Problems" (Agussurja, Cheng, and Lau 2019) also looks at the use of ride-sharing from a hub or station to a passenger's destination. The authors incorporate demand uncertainty and demand batches. The paper uses a two-level planning approach that first selects which requests will be served in a given period and then does the routing. The first-level problem is modeled as a Markov decision process (MDP) and use approximation and other ideas to keep it scalable. The authors apply their approach to a real-world data set from Singapore.

3. Freight-Based Urban Transportation

One theme among the freight-based papers is the same day delivery of goods to the home and the dynamic decision making this requires. Three papers in this special issue examine this question with the use of privately owned vehicles. In their paper "The Same-Day Delivery Problem for Online Purchases," Voccia, Campbell, and Thomas (2019) look at same day delivery within a multi-vehicle dynamic pickup and delivery problem with time constraints. Results involving the value of waiting at the depot and the value of anticipation of requests are discussed. The authors model this problem as an MDP and solve it with a heuristic based on sample scenario planning. Also on the topic of same-day delivery is "Offline–Online Approximate Dynamic Programming for Dynamic Vehicle Routing with Stochastic Requests." Ulmer et al. (2019) focus on dynamic routing policies for a single-vehicle routing problem. The authors introduce temporal and spatial anticipation of service requests within an approximate dynamic programming approach. Dynamic routing policies are obtained with reduced computational requirements for real-time decision making. Also within an approximate dynamic programming setting, van Heeswijk, Mes, and Schutten (2019) look into a variant of the delivery dispatching problem from an urban consolidation center ("The Delivery Dispatching Problem with Time Windows for Urban Consolidation Centers"). Orders are consolidated and dispatched taking into account the orders at hand, the pre-announced orders, and stochastic order arrivals. The authors develop techniques to solve large instances and offer new value function approximations.

When ordering goods online for same-day delivery, crowdsourced delivery is an interesting alternative (Arslan et al. 2019). "Crowdsourced Delivery—A Dynamic Pickup and Delivery Problem with Ad Hoc Drivers" deals with this timely topic. A rolling horizon framework is used to deal with updated information combined with an exact solution approach to solve this new matching problem between packages and available ad hoc (i.e., the crowd) drivers. Results show that using ad hoc drivers can bring significant cost reductions.

When offering delivery services, another challenge is pricing the different delivery time slots, as well as identifying which time slots to tell customers to expect their delivery. "Differentiated Time Slot Pricing under Routing Considerations in Attended Home Delivery" deals with using time slot pricing to influence customer choice behavior with regards to their time slot choices for a day in the near future. Klein et al. (2019) consider price differentiation and routing. Inspired by an industrial problem, the authors show the value of their approach on real-world problem sizes. Assigning time windows to customers to incorporate customer service reliability into routes is the topic of the paper "Assessing Customer Service Reliability in Route Planning with Self-Imposed Time Windows and Stochastic Travel Times." In this paper, Vareias, Repoussis,

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and Tarantilis (2019) propose a number of mathematical models considering stochastic travel times to set reliable customer time windows. A hierarchical solution approach combining adaptive large neighborhood search with an exact solver is developed.

One of the more popular examples of products delivered to the home is groceries. With a grocery distribution context, Hübner and Ostermeier (2019) examine a multi-compartment vehicle routing problem. One vehicle is able to carry different products with different characteristics (e.g., temperature). This creates flexibility but also adds to the routing and scheduling complexity. In their paper "A Multi-Compartment Vehicle Routing Problem with Loading and Unloading Costs," the authors introduce loading and unloading costs into the models and show that the impact of these cost components on the solution are significant.

Finally, Schneider and Löffler (2019) look into joint decision making on the location of depots and the routing of vehicles to serve customers. "Large Composite Neighborhoods for the Capacitated Location-Routing Problem" looks into an effective solution tree-based search approach to deal with this problem. The application is framed within a densely populated urban area.

4. Future Directions

The papers in this special issue highlight important themes that we can expect to develop further at the intersection of (combinatorial) optimization and analytics. In many cases, researchers still seem to not have enough real-life data in order to do their optimization and analytics work. One way to overcome the data problem, and seen in this special issue, is the use of simulation. This generates new data that can be used as inputs and to verify the quality of results recommended by the optimization.

As data becomes more prevalent, we expect to see more work on reinforcement learning in transportation models, e.g., for vehicle routing, such as in Nazari et al. (2018). To the best of our knowledge, only a few other examples of machine-learning focused logistics research are available in the literature (see e.g., Schultz and Sokolov 2018; Kara and Dogan 2018; Bengio, Lodi, and Prouvost 2018).

This special issue also reveals many new operations research models that are likely to be increasingly important. Many see public transportation as currently under-used, so one research problem highlighted in this issue is the use of a smaller public network covering only the high-traffic portions of a city, but connected with small shuttle or car-sharing options to transport passengers to their final destination. This requires the extensive use of data and data-sharing between groups for both effective long- and short-term planning decisions.

The freight-based logistics papers highlight the increasing importance of same-day delivery and the difficult challenges these problems present. Making decisions requires efficient but effective evaluations of the future implications of these decisions. It is still emerging how to make these evaluations both in how to serve customers, pricing, and setting of time windows.

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